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Coastal Zone and Estuarine Studies Division

Research Activities and Accomplishments 1980-89

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Preface

This report summarizes research conducted by Coastal Zone and Estuarine Studies Division staff from 1980 to 1989. Individual scientists and the studies they worked on are identified in the bibliographies. However, the work would not have been possible without the assistance of a large number of unnamed individuals, including the Division's engineering and mechanical staff, numerous technicians and laborers, biometricians, and administrative and clerical staff. Dr. Wesley J. Ebel and Gerald E. Monan served as Division Directors during the reporting period.

Most field projects were cooperative efforts with agencies such as the Bonneville Power Administration, Pacific Northwest Regional Commission, Pacific Northwest River Basins Commission, and the U.S. Army Corps of Engineers. The bibliographies provide details on these collaborations. Contract reports and technical summaries referenced in the bibliographies are available through the Coastal Zone and Estuarine Studies Division in Seattle, Washington.

INTRODUCTION

The principal objective of the Coastal Zone and Estuarine Studies (CZES) Division of the National Marine Fisheries Service (NMFS) is to provide information leading to the protection, development, and balanced growth of important living aquatic resources. Throughout the Pacific Northwest during the 1980s, a number of environmental concerns were brought to the forefront. Of particular significance and interest to CZES Division staff was the increased politcal, scientific, and social emphasis on fisheries enhancement. This enhancement encompasses mitigation for fisheries losses, as well as assessment of environmental effects. The increasing priority placed on these aquatic resources has resulted in conditions conducive to the attainment of CZES Division research goals.

Included among these resources are salmon, steelhead, shad, smelt, sturgeon, oysters, clams, shrimps, crabs, and aquatic plants. Every fishery is a complex of interactions among organisms, the environment, and social values. The role of the CZES Division is to plan, carry out, and report on the research necessary to understand these interactions and to identify and solve problems within them.

Research projects presented in this report have been arranged into five general areas of investigation: Salmonid Migrations of both adults and juveniles; Salmonid Propagation, including reproduction and developmental physiology; Ecosystem Assessments, both broad and species-specific; Environmental Effects; and Technological Contributions. Within each of these categories, the projects discussed represent collaborative efforts between CZES scientists, technicians, and support personnel. In many cases, collaborations extended to other federal, state, and tribal agencies. Each project is summarized in this report, and a bibliography is presented. The objective is to present a survey of the research activities of CZES Division staff during the 1980s, and to identify pertinent reports and publications that will provide additional details where needed.

SALMONID MIGRATIONS

Electronic Surveillance of Adults and Juveniles

Efforts to study salmonid migrations via electronic surveillance during the 1980s included six major research projects and the development of three new research instruments. CZES staff were directly involved with, or assisted in the development of, pulse-coded radio tag systems and passive integrated transponder (PIT) tags for adult and juvenile fish (see TECHNOLOGICAL CONTRIBUTIONS).

In the early 1980s, a series of studies using radio-tagged adult salmonids (*Oncorhynchus* spp.) to evaluate passage facilities at hydroelectric dams on the mainstem Columbia River was concluded. As documented by this research, the behavior of adult salmonids at the dams was used to set operational criteria for adult collection channels and fish ladders. Fish passage times from site arrival to departure were used to evaluate the effects of river flow, spill, and fallback. Information on the routes of tagged fish during dam passage was used to define areas at the dams that warranted structural or operational change.

In 1981, radio tags and airplane surveillance were used to evaluate the effects of zero river flow on the migration of adult salmonids in the Snake River. Water pooled upstream from the dams during periods of low power demand (on weekends and at night) was used for power production during weekdays. Evidence of reduced fish passage was found, and eventually weekend zero flow was curtailed. However, evidence of delays caused by nighttime zero flow was not strong enough to affect restrictions on this practice. The occurrence of nighttime zero flow at Snake River Dams remains

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an important issue. Studies scheduled in the Lower Snake River for 1991-93 will again address this subject.

In 1982, radio tags were used to determine the fate of upriver-bright (adult) fall chinook salmon (O. tshawvtscha) that apparently "disappear" between Bonneville and McNary Dams on the Columbia River. The results from this study greatly increased our understanding of migration patterns for these fish. For example, results indicate that not all upriver-brights are destined for spawning areas above McNary Dam.

From 1982 to 1984, the miniature radio tag was used to evaluate passage routes of salmonid smolts at John Day Dam. Migration routes of radio-tagged smolts were correlated against spill patterns and timing to determine the most efficient method of passing smolts through the spillway. Fixed-site monitor development during these years led to the possibility of determining passage locations for large groups (100 +) of radio-tagged smolts without individually tracking fish from boats.

In 1985 and 1986, tests were conducted at Lower Granite Dam on the Snake River to evaluate the potential for using the miniature radio tag and fixed-site monitors. Equipment was evaluated for accuracy in estimates of passage location, fish guidance, collection efficiency, and survival. Results indicated that tags should not be used with smolts smaller than 170 mm fork length (which includes most chinook salmon smolts) and that the high flows below Lower Granite Dam move dead radio-tagged smolts downstream at the same rate as live smolts. Because of these findings, radio telemetry techniques have not been pursued with salmonid smolts.

In 1987, the first field study utilizing the passive integrated transponder (PIT) tag system was conducted to evaluate spring chinook salmon survival in the Lower Granite Dam reservoir and turbine units. However, researchers encountered serious questions relating to the assumptions required for accurate survival estimation. These questions led to evaluations in 1988 and 1989 of the factors that affect collection rates. These evaluations led to the conclusion that factors such as source of test fish, test group release time, and short-term changes in spill rates may confound survival estimations. Thus survival studies were postponed. However, Division personnel significantly increased the efficiency, speed, and range of the PIT-tag detection system during this period. Development of precise and accurate systems to detect adult salmonids in the fish ladders of Columbia River dams continues.

In 1989, radio tagging of adult steelhead (O. mykiss) and spring chinook salmon began in the Yakima River. This study is part of a multiagency program (Yakima/Klickitat Production Program) to reestablish anadromous runs in remaining spawning areas. The radio-tag information will help determine how many wild stocks still exist in the Yakima system, and where brood-stock removal should occur. This research is projected for 4 years in the Yakima River with subsequent studies in the Klickitat River.

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Migration Raters of Juvenile Salmonids

The construction of mainstem dams on the Columbia and Snake Rivers has increased downstream migration time and reduced survival for juvenile salmonids. In the early 1980s, the CZES Division continued studies evaluating the effects of impoundments on the migrational characteristics and survival of salmonids in the Columbia-Snake River system. This involved smolt monitoring at mainstem dams and mark-release studies to evaluate travel time/survival/flow relationships. The results of these studies helped CZES investigators to create and define an amount of water to be set aside for a "water budget" to flush salmonid smolts downstream. Smolt monitoring responsibilities were largely transferred to the Fish Passage Center in 1983. Concurrently, studies were conducted on radio tracking of salmonid smolts and on smolt passage behavior and flow-net relationships. Study results helped CZES investigators to better describe smolt migrational characteristics. Further information on juvenile salmonid migration rates came from studies conducted at Jones Beach, Oregon, at the head of the Columbia River estuary (see the following report on Columbia River Estuary and Ocean Plume).

In the latter part of the decade, the **Division focused** migrational studies on the relationship between smolt physiology and migrational behavior. Results indicated that physiological and behavioral development of yearling chinook salmon changed little while fish were at the hatchery. However, substantial physiological changes were observed when migrants were recaptured downstream at collector dams. These observations led to research to determine if smolt development could be accelerated at the hatchery. A strong association was discovered between accelerated development and increased migration rates, fish guidance efficiency, and subsequent survival.

Beginning in 1988, an advanced photoperiod treatment was applied to a test group of yearling chinook salmon at Dworshak National Fish Hatchery. Lights were suspended over a raceway containing PIT-tagged yearling chinook salmon. Photoperiod was advanced 3 months, and fish were exposed to advanced light conditions for 14 weeks. Physiological development, migrational characteristics, and detection rates were then compared with a PIT-tagged control group reared under ambient photoperiod conditions. The results demonstrated that yearling chinook salmon exposed to advanced photoperiod were more physiologically advanced at release (as evidenced by higher gill Na^+-K^+ ATPase levels). These fish also migrated faster and were detected at a higher rate downstream. During 1989 and 1990, this study was expanded to include additional photoperiod treatments and an increased water temperature treatment near the time of release. The purpose of the temperature treatment was to duplicate water temperatures that migrating smolts typically encounter after leaving the hatchery. The results again demonstrated that advanced photoperiod treatment accelerated smolt development at the hatchery and resulted in increased migration and detection rates downstream. Addition of the water temperature treatment near the time of release may have further accelerated smolt development. Temperature treatment may also help to increase migration and detection rates.

In the coming years, Division personnel will be investigating other methods of increasing smolt development and migration rates in hatchery populations. Methods to be tested include decreasing rearing density and postponing release dates to allow more complete smolt development.

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Juvenile Bypass Development

During the 1980s, research to evaluate, estimate potential guidance of, and improve juvenile collection and bypass systems was conducted at all four dams on the Snake River, and the four largest dams on the Columbia River. The Columbia Basin Fish and Wildlife Authority (CBFWA) has an interim goal of 50 and 70% and a long-term goal of 70 and 80% fish guidance efficiency **(FGE)** at hydroelectric projects for subyearling and yearling migrants, respectively. None of the projects currently meet the long-term standards. The CZES Division's research efforts are directed toward developing the means to achieve these goals.

With the guidance systems of the early 1980s, FGEs at Lower Granite and Little Goose Dams for yearling chinook salmon and steelhead were approximately 60 and 70%, respectively. A raised operating gate was tested at Lower Granite Dam (1985) and at Little Goose Dam (1986) as a means to improve FGE. At both projects, significant FGE increases of 8 to 10% were obtained for chinook salmon and steelhead; but even with the increases, the **FGE** did not meet the long-term CBFWA goals. In view of these results, the U.S. Army Corps of Engineers (COE) will raise the operating gates at Lower Granite and Little Goose Dams.

In 1987, a bar screen deflector was placed in the fish screen slot at Lower Granite Dam to test **FGE** applications for an extended submersible traveling screen (STS). The extended STS concept provided overall guidance exceeding 80% for steelhead. Guidance for yearling chinook salmon approached 80%, although an overall 80% average was not obtained. The depth distribution of juvenile yearling chinook salmon approaching turbine intakes during early migration was too great for the guidance device to intercept 80% of the fish. The current hypothesis is that depth distribution is biologically determined.

In 1987, raised operating gates were tested at McNary Dam. The FGEs for yearling chinook salmon and steelhead were increased to greater than 80%. Based upon these results, the COE is studying the feasibility of raising operating gates at McNary Dam.

Research was also conducted during the summers of 1986 and 1987 on migrating subyearling chinook salmon. In addition to the raised operating gate used with spring yearling migrants, a deflector was added to the trashrack to increase the percentage of intercepted fish. Neither of these two modifications substantially improved FGEs, which ranged from 25 to 45%.

From 1985 to 1986, the juvenile bypass system at John Day Dam was evaluated. Fish guidance efficiency for steelhead exceeded 80%, yearling chinook salmon **FGE** was 72%, and subyearling chinook salmon FGE ranged from 25 to 45%.

In 1988, Bonneville First Powerhouse FGE was evaluated for the first time for summer subyearling chinook salmon migrants. Guidance averaged 11%. This was similar to the FGEs obtained in prototype tests at The Dalles Dam in 1985 with standard and lowered STSs (8 and 14%, respectively).

Bonneville Second Powerhouse FGEs for summer subyearling chinook salmon migrants under standard powerhouse conditions were less than 20%, but have been as high as 35% with a number of experimental modifications.

Research efforts during summer have been unsuccessful in meeting the minimum CBFWA guidance levels for subyearling chinook salmon migrants at any hydroelectric project.

No STS bypass facilities exist at Lower Monumental, Ice Harbor, or The Dalles Dams; however, between 1985 and 1987 prototype studies were conducted at each with a lowered STS and raised operating gate (where appropriate) to determine potential guidance levels. Steelhead FGEs exceeded 80% at Lower Monumental and Ice Harbor Dams, but were only 70% at The Dalles Dam. Yearling chinook salmon guidance levels were between 73 and 77% at Lower Monumental and Ice Harbor Dams, but only 60% at The Dalles Dam.

At Bonneville Second Powerhouse, experimental modifications to the project have shown the potential to increase FGE for yearling chinook salmon from approximately 20 to 70% through the use of lowered STSs, turbine intake extensions, and streamlined trashracks.

During the latter part of the 1980s, research was initiated to evaluate the relative survival of juvenile salmonids passing through the spillway or the second powerhouse turbines or bypass system at Bonneville Dam. Differences in survival were detected, but only preliminary information was available during the period of this report. Work on this study is continuing.

An evaluation of all of the research efforts showed that each hydroelectric project is unique, and solutions that might be effective at one dam may not be appropriate at another. Furthermore, fish behavior and physiological state apparently play a large role in successful fish guidance. Even the most mechanically up-to-date bypass systems may not be successful at guiding fish who are not physiologically or morphologically prepared to migrate.

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Juvenile Passage Survival at Bonneville Dam

In 1987, the CZES Division began a multiyear study to evaluate survival of subyearling fall chinook salmon passing Bonneville Dam. Detailed survival information was critically needed for fish management in relation to power production at Bonneville Dam. Previous survival studies at this project were done in the 1970s, prior to construction of spillway deflectors (to minimize supersaturation of atmospheric gases) and the Second Powerhouse with its downstream migrant bypass system.

During this 4-year study, nearly 8 million fish were marked and released at selected locations above and below the dam. Test releases were made so that fish passed the dam via the Second Powerhouse turbines, bypass, or spillway. Additional releases were made below the dam in the tailrace (near the egress of the bypass system) and 2.5 km downstream from the dam. Initial results were based on seine recoveries of marked fish 157 km downstream from the dam at the head of the Columbia River estuary on Jones Beach (River Kilometer 75). These results indicated no survival advantage to fish using the bypass system compared to those passing through the turbines. Differences between recoveries of bypass- and turbine-released fish were about 10.9, 13.6, 3.3, and 2.5% in the study years 1987, 1988, 1989, and 1990, respectively, with percent recovery of turbine-released fish always exceeding that of bypass-released fish.

Although these results were preliminary (pending results of adult returns to be monitored until 1994), they suggested a problem of such importance that research emphasis was shifted to investigate the specific cause of poor bypass survival. Assessment of stress and physical injuries related to using the bypass system is currently being conducted to identify that segment of the system causing survival problems. Future research will be designed to examine passage survival differences between the first and second powerhouses and to further identify the causes of low survival. These data will provide guidelines for dam operational procedures to maximize survival until bypass survival problems can be corrected.

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Transportation of Juveniles

Since 1983, **CZES Division personnel have** conducted studies to isolate and eliminate areas of stress and injury in fish transportation systems of the Snake and Columbia Rivers. The Division has conducted barge transport index marking since 1983 at Lower Granite Dam, and marking and transport research since *1986* at Lower Granite and McNary Dams. Recently, research has focused on the potential of using PIT tags (see TECHNOLOGICAL CONTRIBUTIONS) to evaluate transportation of wild spring chinook salmon.

A significant accomplishment resulting from research on stress was the refinement of the seawater challenge technique. This technique provides rapid measurement of relative stress among treatment groups of juvenile salmonids. This system produces more rapid analysis than the conventional measurements of stress, which require assay of blood cortisol or electrolytes. Conclusive data can be obtained within 48 hours for most seawater challenge test situations, whereas blood chemistry analysis usually takes weeks. Several studies using this technique were completed to isolate areas of stress in bypass, marking, and transportation systems. Modifications to the systems were recommended and implemented. As a result of these studies, CZES researchers:

1) Determined that preanesthetizing juvenile salmon before handling and marking significantly reduces stress.
2) Isolated stress areas in the bypass system at Lower Granite Dam and recommended successful corrections.
3) Provided stress measurements for evaluation of traveling screens, vertical barrier screens, and orifice configurations.

4) Determined that juvenile spring chinook salmon, when confined with juvenile steelhead, exhibited specific stress. When possible, steelhead are now separated from chinook salmon in holding raceways and transport vehicles.
5) Determined that load densities of 0.5 pound fish/gallon were not significantly more stressful during transport than lower densities, confirming this density as safe for general operating procedures.

In addition to implementing the seawater challenge technique to measure stress, long-term artificial seawater rearing in a closed recirculation system was employed in 1984, 1985, and 1986. The purpose of the system was to measure subtle effects caused by stress or disease in chinook salmon collected at Lower Granite Dam. The experimental design called for treatment groups to be reared for 120 days or longer to determine effects on growth and survival. Results suggested that bacterial kidney disease (BKD) was the primary factor affecting long-term survival of hatchery spring chinook salmon. Bacterial kidney disease may be the major limiting factor in the early ocean survival of hatchery spring chinook salmon, whether collected and transported or not.

Fish transportation studies were conducted to determine the effects of barging steelhead directly from Dworshak National Fish Hatchery (NFH) and transporting sockeye (O. nerka) and chinook salmon from upstream dams to release locations downstream from Bonneville Dam. Analyses of adult return data from these experiments continue to show the benefits of transportation. The data are especially strong for steelhead and fall chinook salmon. Earlier data on spring chinook salmon were highly variable from year to year, but generally indicated positive effects from transport. Recent adult returns of spring chinook salmon, marked at Lower Granite Dam in 1986, showed a transport benefit ratio of 1.6 to 1, with a 95% confidence interval of 1.01-2.47 to 1. Preliminary analysis of returning adult steelhead data, obtained from the direct barging of Dworshak NFH stocks, indicates that barging can substantially increase returns to the fishery as well as to the hatchery. Steelhead barged in the middle of the outmigration (25 April and 19 May) returned at a higher rate than those barged earlier (19 April) or later (31 May). Rate of return appears related to the level of smoltification at the time of barging. The gill Na^+-K^+ ATPase profiles from samples of treatment groups appeared to support this observation.

Studies to determine the potential of using PIT tags to evaluate transportation of wild spring chinook salmon have provided important information on recovery rates and on the life history of these fish. For example, it is now believed that the outmigration timing for these fish at the collector dams is generally later and more protracted than for their hatchery-reared counterparts. In addition, a PIT-tag detection/diversion system, developed for use at collector dams, is capable of automatically diverting PIT-tagged fish back to the river with a high level of efficiency.

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Columbia River Estuary and Ocean Plume

The 1980s saw the culmination of extensive multiyear juvenile salmonid sampling programs conducted throughout the Columbia River estuary and in the coastal areas adjacent to its mouth. In the initial stages of the study, sampling procedures for juvenile salmon and steelhead entering the Columbia River estuary and ocean plume were developed and refined, and 33 sampling sites were evaluated for potential to provide representative catches of most salmonid stocks migrating into the estuary. From 1978 to 1980, there were two primary sampling sites: 1) the upper extreme of the estuary at Jones Beach (River Kilometer 75) and 2) near the lower margin of the estuary at McGowan, Washington (River Kilometer 16). Additional sites throughout the estuary, river mouth, and in the Columbia River coastal near-shore plume were sampled intermittently to provide additional information about movement through the estuary. From 1981 to 1983, sampling continued at the Jones Beach site.

These research projects have yielded valuable information concerning 1) variables which affect timing and movement of juvenile salmonids to and through the estuary and through coastal marine waters of Washington and Oregon; 2) recovery rates and their relationship to river flow, release site, release date, and physical condition of migrants; 3) survival trends during riverine migration associated with river conditions, cultural treatments, and physical condition of migrants, and the relationships of these trends with survival to adulthood; 4) ecological impacts during migration through the estuary; and 5) comparisons of survival and contributions between wild and hatchery fish stocks.

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SALMONID PROPAGATION

Captive Brood Stocks (Reproductive Physiology)

Some genetically distinct races of wild salmon and steelhead in the Pacific Northwest are severely depleted or nearly extinct. In accordance with the Endangered Species Act, the NMFS is responsible for developing and implementing recovery programs for stocks of anadromous salmonids listed as threatened or endangered. One method for preserving listed wild stocks is to maintain them in total culture until they can be returned to their streams of origin.

The CZES Division has ongoing programs that serve as a model for maintaining seriously depleted or threatened stocks of salmonids in captivity throughout their entire life span. The goal of the captive brood-stock programs is to develop husbandry techniques that ensure good health and high survival of selected races of salmonids while maintaining genetic integrity and variability.

Since 1979, the Division brood-stock egg production programs have focused on restoration of threatened runs of Atlantic (*Salmo salar*) and Pacific salmon. The captive brood-stock concept involves the rearing of smolts to maturity. The techniques employed can produce up to 200 spawning females from every female parent. In addition to quickly producing large numbers of eggs, a further benefit of brood-stock rearing has been the compilation of husbandry data, including information on physiological development during an otherwise unobservable period of the fish's life-cycle. These data are of considerable value to fisheries scientists.

The culturing of Atlantic and Pacific salmon brood stocks and its associated research have provided cost-effective methods of maintaining egg banks of depleted populations of salmon. In addition, methods have been developed for the diagnosis, treatment, and prevention of common infectious and nutritional diseases. The existence of previously undescribed parasites and pathogens has been documented as well. Also, the CZES Division brood-stock program developed or refined a number of techniques for the induction of synchronous maturation and ovulation in marine cultured salmon. These techniques result in a greater egg-take (since prespawning mortality is reduced or eliminated) and more efficient use of staff and resources.

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Improved Quality of Hatchery Smolts (Developmental Physiology)

In the late 1970s, returns of salmon and steelhead to the Columbia River Basin declined dramatically. Some scientists in the CZES Division believed that smolts of inferior quality were being released from hatcheries and that the lack of high-quality smolts in the system was contributing to the decline in adult returns. In 1978, the Division became involved in a 3-year study assessing the smolt quality of juvenile anadromous salmonids and determining the role of smolt quality in survival to adulthood. This study investigated the status of smolt development in salmon and steelhead from several Columbia River Basin hatcheries. Biochemical measures were used as development indicators and compared to survival and growth performance in seawater net-pens. When the study ended in 1981, the data indicated that fish were being released from hatcheries under conditions of suboptimal smolt development. Also, survival could be increased if release strategies were altered to correspond more closely with smolt development. The CZES staff recommended that smolt development be more closely monitored at rearing facilities and that release timing be adjusted to smolt development to maximize survival.

Throughout the 1980s, studies on smolt development at laboratories and production facilities continued. Researchers of the CZES Division believe that smolt development is crucial to the survival of cultured salmonids. Managers need objective measures of smolt development when evaluating attempts to improve survival, such as making adjustments in rearing strategies. Although a number of tests evolved that can index smolt development, two received major emphasis: 1) measurements of gill Na^+-K^+ ATPase

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activity, an enzyme that is closely associated with the ability to adapt to seawater, and 2) measurements of plasma thyroxine (T_3 and T_4) concentrations, which are involved in many developmental steps occurring at the time of smolt transformation. Both of these factors show significant increases during the transition from parr to smolt.

Using various measurements of smolt development, the following relationships were discovered during the past 10 years:

- The act of migration greatly increases gill Na^+-K^+ ATPase activity, suggesting migration plays an important physiological role in the development of seawater tolerance.
- A dramatic drop in the immune response is associated with an increased smolt development.
- High pond density of coho (O. kisutch) and spring chinook salmon suppresses gill Na^+-K^+ ATPase activity and is associated with decreased adult recoveries.
- Blood levels of insulin increase during the initial stages of smolt development; also, other changes in the endocrine system occur (e.g., increases in plasma cortisol, growth hormone estradiol, norepinephrine, and epinephrine).
- Gradual adaptation to salt water of increasing salinities results in much greater survival than direct entry into full strength seawater, **especially** when fish show minimal smolt development.
- When fish are released prior to indications of smolt development, they migrate seaward slowly in near-shore areas, whereas more fully developed fish tend to migrate more rapidly and in center stream.
- Fish with elevated levels of gill Na^+-K^+ ATPase activity tend to be guided more effectively by fish by-pass screens than fish with low levels of activity.
- Over a 5-year period, adult contributions of fall chinook salmon were correlated with prerelease smolt development.
- Subjecting yearling spring chinook salmon to advanced photoperiods for 3 months prior to release resulted in greater smolt development and more rapid downstream migration. This was indicated by greater collection efficiency at collector dams in the Columbia River.

- Peak plasma thyroxine levels in some populations of salmonids occur during the full moon.
- Low levels of copper (Cu^{++}) inhibit gill Na^+-K^+ ATPase activity associated with smolt development and seawater adaptation, but not the activity present in parr.
- Experiments with the antibiotic actinomycin D indicated that the gill Na^+-K^+ ATPase activity associated with smolt development and the Na^+-K^+ ATPase activity associated with adaptation to seawater are probably related to the same enzyme.
- Fish experience weight and length loss when subjected to a Na^+-K^+ ATPase 24-hour seawater challenge. The amount of weight or length lost is related to the level of gill Na^+-K^+ ATPase activity.

Using gill Na^+-K^+ ATPase activity to assess smolting, a new spring chinook salmon release strategy was evaluated. At the Little White Salmon National Fish Hatchery, some returning adult spring chinook salmon were placed under controlled lighting. Day lengths were artificially reduced, causing the fish to spawn about 1 month early. The resulting progeny, being larger than those from normally spawned adults because of increased growing time, exhibited signs of smoltification in their first spring (age 0). A cooperative study with the hatchery showed that release of these 0-age fish resulted in a significant adult contribution and was an efficient method of supplementing production. Release of 0-age spring chinook salmon is now being tested at other hatcheries to investigate the possibility of using this strategy to augment runs.

In 1987, the Division became involved in an extensive study with the Washington Department of Fisheries to determine why there was differential survival in coho salmon between two hatcheries in the Grays Harbor area of western Washington. The study produced information on the possible roles of smoltification, health, predation, migration, seawater adaptation, pulp mill effluents, and other factors in survival.

In the spring of 1989, Division scientists began a cooperative study to assess the quality of spring chinook salmon being released from five Columbia Basin hatcheries. Tests to determine the developmental status and general condition of fish being released from these hatcheries are being made. Since groups of fish being studied are coded-wire tagged, adult contribution will be correlated with all parameters being measured.

Much progress was made during the past 10 years in determining the relationships between smolt development in hatchery populations and post-release migratory performance and survival. Although we now know that the degree of smolt development at the time of release significantly affects migration behavior, its effect on survival is not yet known. There is evidence that the more fully smolted fish are at the time of release, the greater their chance of survival. Present studies should provide further evidence and help determine just how important it is to release fish of high quality from our public hatcheries.

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Sockeye Restoration

The CZES Division is evaluating the feasibility of restoring anadromous sockeye salmon to the Yakima River Basin in Washington. The study focuses on Cle Elum Lake, which is approximately 500 river miles from the ocean. Cle Elum is the largest of five lakes in the Yakima River Basin that once served as nursery areas for sockeye salmon. Since the 1930s, Cle Elum Lake has been impounded for irrigation by a 130-foot high earth and concrete dam constructed on the historic lake outlet. Built without provision for juvenile or adult salmon passage, this dam blocks access to a considerable area of spawning and rearing habitat. The restoration feasibility study involves development of fish husbandry techniques for providing healthy juveniles from a donor stock to rebuild this extinct run. This requires evaluation of the outmigration of fish previously outplanted to the Yakima River Basin.

Fish husbandry investigations involve the collection and spawning of adult sockeye salmon from the Wenatchee River, Washington, and incubation of eggs and rearing of juveniles at the CZES Division Stock Restoration Laboratory at the Northwest Fisheries Science Center in Seattle, Washington. Since 1987, up to 520 adult sockeye salmon have been captured yearly during late July and early August. Fish are captured at the Tumwater Dam fishway on the Wenatchee River and transferred to net-pens in Lake Wenatchee. There they are held to maturity, until late September or early October. After spawning, the green eggs are transported to the Seattle laboratory. Yearly adult capture-to-spawning survival has ranged from 70 to almost 98%.

In 1987 and 1988, all net-pen spawners were documented as being free of infectious hematopoietic necrosis (IHN) virus although the incidence of IHN in the spawning rivers in the area was almost 90%. In 1989 and 1990, IHN was detected in many of the adult fish at the net-pen complex. It is believed that the IHN infections at the net-pen site may have been horizontally transferred from an infected sockeye salmon captured during trapping. However, it is possible that the infection was spread from a natural reservoir in the lake. Eggs from net-pen spawners were fertilized and reared at the Seattle laboratory, and all egg groups were incubated separately. Only progeny from parents certified as IHN negative were used in the restoration project. Progeny with one or more parent that was IHN positive were returned to the Washington Department of Fisheries. All eggs had been disinfected in iodophor at spawning, and the resultant juveniles remained negative for IHN through culture; this suggests that vertical (egg-associated) transfer of the virus from parent to progeny was avoided.

The immediate goal of the restoration project is to determine if introduced sockeye salmon can successfully migrate from Cle Elum Lake under the irrigation discharge conditions that now exist. Approximately 90,000 juvenile sockeye salmon, certified as IHN negative from the 1987 and 1988 broods, were reared in Seattle and released in the Yakima River Basin from fall to spring in 1988-89 and 1989-90. Fry to smolt survival ranged from about 70 to 80% for these groups. All fish were freeze branded and coded-wire-tagged, and a portion (3 to 5%) were PIT-tagged.

The 1989 to 1990 study relied on direct capture of juvenile sockeye salmon from the lake in traps. A floating Merwin-type (near-surface, near-shore) trap was located in the forebay near Cle Elum Dam and an inclined plane trap was located at the outfall from the dam. Evaluation of downstream movement was documented through recaptures at fish collection facilities at Prosser Dam on the lower Yakima River (about 150 miles downstream from Cle Elum Lake) and at McNary Dam on the mainstem Columbia River.

The data suggest there are no severe blockages to migration of sockeye salmon in the free-flowing sections of the Yakima River System. Most groups released to the free-flowing Cle Elum River below the dam moved downstream to the ocean at rates of 20 to 30 miles per day. There were large numbers of juvenile sockeye salmon in the lake near the outlet structure during the springtime study period. However, very few of these fish were recaptured below the dam. Our data indicated that the major obstacle to restoring a run at Cle Elum Lake is fish attraction to and passage through the outlet structure at Cle Elum Dam.

Coastal Zone and Estuarine Studies researchers believe it is possible to provide a flow pattern discharge from Cle Elum Lake that will attract outmigrants away from the outlet structure. In 1991, CZES investigators will **evaluate** links between water discharge patterns from the dam, sockeye salmon distribution patterns in the lake, and springtime smoltification and outmigrant readiness. These studies should provide information for the design of a smolt by-pass system to provide optimal outmigration under the irrigation water discharge pattern at Cle Elum Dam.

The sockeye salmon restoration program provides a model for linking donor brood-stock concepts with habitat restoration efforts for depleted stocks.

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ECOSYSTEM ASSESSMENTS

West Coast Estuarine Inventory

In 1988, the CZES Division entered into a cooperative study with NOAA's National Ocean Service to compile a summary data base on living marine resources in selected estuaries of Washington, Oregon, and California. This data base is the West Coast component of NOAA's National Estuarine Inventory. The final West Coast inventory, in atlas form, presents a review of available data on the distribution, abundance, and life-history of 47 economically and ecologically important species from 32 West Coast estuaries. The completed and computerized data base enables comparisons between species, groups of species, specific life-stages, estuaries, and geographic regions.

This inventory is the necessary first step in providing documentation which will allow coordinated regional management strategies. When complete, the study will provide a ready reference to key organisms and their distributions and will direct researchers and resource managers toward estuaries and species about which more data are required.

All of 1989 (and part of 1990) was spent collecting data on various species and estuaries. Much of this information was gathered from important unpublished and "gray literature" sources authored by a variety of groups and individuals. Of special value was the input from meetings with regional estuarine experts who provided firsthand knowledge of specific species and estuaries.

In March 1990, a report presenting a summary of distribution and abundance data was completed and distributed. In 1991, a report was produced that presents species life-history summary data and some analysis of distribution and abundance data. These reports were followed by a publication in 1992 that evaluates the relationship between estuarine physical factors and estuarine fish biogeography. Currently, a publication that discusses spawning escapement and hatchery production of salmonids in West Coast estuarine basins is in review.

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Columbia River Estuary Long-Term Management Strategy

Each year, the COE dredges and disposes of more than 1.5 million m^3 of sediment from the navigation channel between River Kilometers 7 and 46 in the Columbia River estuary. Existing upland dredged-material disposal sites are almost filled to capacity, and options for the disposal of this volume of sediment are presently extremely limited. Accordingly, in 1988 the COE initiated a study to develop a Long-Term Management Strategy (LTMS) for dredging and disposal operations in the Columbia River estuary. The goal of the LTMS is to ensure that future dredging and disposal activities will be economical, minimize adverse environmental impacts, and take advantage of opportunities for beneficial uses of dredged material.

One of the major concerns associated with new in-water disposal sites, especially when creating islands, is the effect on aquatic biological communities. To address this concern, the CZES Division initiated a study to assess aquatic resources in intertidal and subtidal habitats at or adjacent to five present or potential disposal areas in the Columbia River estuary: Desdemona Sands, Taylor Sands, Rice Island, Miller Sands, and Jim Crow Sands. Specific objectives of the study were 1) to describe bottom sediment characteristics and the benthic invertebrate and fish communities at each area and 2) to compare bottom sediment characteristics, benthic invertebrate, and fish communities at Millers Sands at present with those that existed from 1975-77. The comparison will weigh the effects of the marsh and lagoon at Miller Sands, which was created with dredged material from 1975 to 1976.

Benthic samples and fishes were collected at the five study areas in the Columbia River estuary during four surveys in 1988 and

1989. All five areas are productive estuarine habitats. Miller Sands and Jim Crow Sands in particular appear to be important feeding and rearing areas for several species of fishes, including juvenile chinook salmon, starry flounder (*Platichthys stellatus*), and peamouth (*Mylocheilus caurinus*).

Fish and benthic invertebrate densities were higher in 1989 than in 1975 to 1977 at the Miller Sands lagoon, suggesting that the creation of the marsh and lagoon was a beneficial use of dredged material. However, multiple years of sample collection and analysis will be required to determine if measured increases in abundances of fishes and invertebrates were strictly the result of habitat changes or were due to natural, interannual cycles in abundances of species.

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Impacts of Coastal Dredging and Dredge Disposal

During the 1980s, the CZES Division conducted a number of field surveys to assess the abundance and habitat of benthic invertebrates, demersal fishes, and large epibenthic organisms at key locations along the Washington and Oregon coasts. Information provided by these surveys was instrumental in decisions by the COE and the Environmental Protection Agency (EPA) on where to conduct dredging activities and locate dredged-material disposal sites.

The Division studied demersal fish and benthic invertebrate communities at four interim ocean dredged-material disposal (ODMD) sites along the Oregon coast, including sites off Tillamook, Depoe, Siuslaw, and Umpqua Bays. Two surveys (September 1984 and January 1985) indicated that the benthic invertebrate population was greater off Tillamook Bay than at the other three sites. The high concentrations of demersal fishes and benthic invertebrates found off Tillamook Bay led to a third survey in July 1985. The results of these three surveys suggested that very high densities of fishes, crabs, and benthic invertebrates occur annually at the Tillamook Bay ODMD site. Examination of additional sediment samples collected off Tillamook Bay in May 1988 indicated a possible reduction in benthic invertebrates 4 km offshore at an approximate depth of 60 m. Division personnel conducted a fourth survey at the extended Tillamook Bay offshore dredge-disposal site in September 1988. Results of this survey were used to aid in determining the suitability of the extended bay as a disposal site for bay sediments and to establish baseline data for future monitoring.

In 1985, at the request of EPA and the Seattle District COE, the Division surveyed a proposed interim ODMD site off Willapa Bay, Washington. The benthic invertebrate community, sampled with a box corer, was high in both numbers of species and densities of individuals. The benthic invertebrate densities off Willapa Bay were much higher than typically found in the Washington-Oregon nearshore environment and resembled those reported in studies of Grays Harbor, Washington, and Tillamook Bay, Oregon, ODMD sites. These three estuaries have extensive mud flats with abundant microalgae and eelgrass. The cause of high invertebrate densities is unknown, but the contribution of primary production from the adjacent estuaries is a probable factor. The Division recommended that these areas not be used for disposal of dredged materials until after more intensive studies are complete. These areas would not be suitable unless it could be shown there would be no severe impacts to estuarine and marine fisheries.

Additional studies concerning the impacts of dredging and dredge disposal on the benthic community were conducted near Westport and Coos Bay, Oregon. Each of these projects resulted in specific recommendations regarding the location of dredging activities and future research needs.

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Columbia River Estuary Data Development Program

In 1980 and 1981, CZES Division personnel participated in the Columbia River Estuarine Data Development Program (CREDDP), by conducting monthly field surveys throughout the Columbia River estuary. Using trawls, beach seines, and purse seines, more than 75 fish species were found in collections from 49 estuarine locations.

The results of this study demonstrated that the Columbia River estuary is an important sanctuary for juvenile fish. Also, the composition of species-groups in the estuary is most influenced by seasonal cycles in the life history and migration of these fish. The most complex composition and distribution were noted in summer. River flow and estuarine salinity appeared to have a strong secondary effect on fish distributions. Finally, within salinity zones, distribution of fishes was related to habitat type. Nearshore, bay, pelagic, and near-bottom areas had slightly different fish assemblages. The maximum number of fish usually paralleled the maximum concentration of zooplankton and epibenthic organisms, the principal fish foods in the central estuary and protected bays.

In addition to the final CREDDP report, another report was based on the CREDDP surveys and evaluated the diets of 25 fish species from demersal, pelagic, and intertidal habitats of the Columbia River estuary. The following are among the findings: groups of fishes with similar diets were distinct in every season; some fishes showed large seasonal variations in diet; and, in general, diets appeared to be determined by the seasonal abundance of prey. Despite the similarities in diet between species, little competition was indicated and this may have been the result of high concentrations of few species of prey.

Also based on results of the CREDDP surveys was a separate report on the diet of juvenile white sturgeon (*Acipenser transmontanus*) in the lower Columbia River and estuary. Sturgeon lengths ranged from 5 to 130 cm (total length). Sturgeon diets varied with area of capture, season, and size. The amphipod *Corophiumsalmonis* was the most important food item, but it was less important for larger sturgeon (greater than 80 cm total length) and those from the lower estuary; these sturgeon consumed larger invertebrates and fish. In general, prey diversity increased with sturgeon size and nearness to the river mouth.

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Columbia River White Sturgeon

The white sturgeon is an increasingly important recreational and commercial species in the Columbia River and its estuary. Because of concern about the demise of this species in certain areas of the Columbia River Basin, the Bonneville Power Administration (BPA) held a workshop in 1985 to define and prioritize research needs. Subsequently, in July 1986 BPA funded a 5-year study of white sturgeon in the Columbia River, covering the entire reach of river downstream from McNary Dam. The purpose was to determine the impact of development and operation of the hydropower system on this species. The study was undertaken in cooperation with the Oregon Department of Fish and Wildlife (ODFW), the Washington Department of Fisheries (WDF), the U.S. Fish and Wildlife Service (FWS), and the National Marine Fisheries Service (NMFS).

The CZES Division is responsible in part for two of the four major objectives of the study: 1) to describe the reproduction and early life history characteristics of white sturgeon populations and 2) to define habitat requirements for spawning and rearing of white sturgeon and quantify the extent of habitat available. The Division's research is being conducted in the Columbia River downstream from Bonneville Dam (RKm 233). When the study began, this was the only reach in the Columbia River system known to support all developmental stages of white sturgeon in sufficient numbers to provide a control against which habitat use and availability in other reaches of the river could be compared. In addition, sturgeon downstream from Bonneville Dam have unrestricted access to the Pacific Ocean and, therefore, may exhibit characteristics of sturgeon stocks that existed prior to dam construction.

Data collected by the CZES Division and WDF ("control data") will be compared to similar data collected by FWS in the impoundments upstream from Bonneville Dam. These comparisons will help determine the impact of hydropower development and operation on spawning, early life history stages, and juveniles of white sturgeon in the impoundments. Initial activities in the study included a literature review and the testing of sampling gear. Field work was conducted from 1987 through 1991 and will resume in 1993.

Research conducted to date has yielded considerable information. Downstream from Bonneville Dam, white sturgeon typically spawn from late April through late June or early July at water temperatures ranging from 10° to 18°C. Spawning occurs from the dam to points at least several kilometers downstream, in areas with high water velocity and a cobble or boulder bottom. Stage 2 (freshly fertilized) white sturgeon eggs were collected in areas with mean water column velocities from 1.2 to 2.8 m/s at depths from 4.3 to 21.3 m. In 1987 and 1988, white sturgeon larvae were collected more than 48 km downstream from Bonneville Dam. In 1989, a higher flow year than 1987 and 1988, one larva was collected more than 56 km downstream from Bonneville Dam. Small young-of-the-year (YOY) white sturgeon were collected in the upper Columbia River estuary (River Km 50) in 1989; presumably these YOY had been transported as larvae to the upper estuary, a freshwater environment, before metamorphosing.

Catches of juvenile white sturgeon in the Columbia River downstream from Bonneville Dam were patchy. Catch data indicated that juvenile white sturgeon tended to be more abundant in water 9.1 m and greater in depth, at least during daylight. Because of the protracted spawning period and different environmental conditions, there can be large variations in lengths of white sturgeon from a specific year class. These variations precluded separation of white sturgeon into year classes except for the very young. The YOY catches were relatively low from 1987 to 1989, ranging from 11 in 1988 (less than 1% of total catch) to 111 in 1989 (4% of total catch). Data from 1989 indicated YOY growth was relatively good, with mean fork length increasing from 85 mm in July to 234 mm in October.

Since white sturgeon is a demersal species, benthic surveys were conducted in conjunction with juvenile sampling to determine the relationship between white sturgeon population densities and benthos. However, these survey data did not indicate a strong relationship between white sturgeon population densities and benthic invertebrate population densities.

Feeding habits of juvenile white sturgeon were examined in 1988 from two locations in the Columbia River downstream from Bonneville Dam. Results from stomach analyses indicated that juvenile white sturgeon fed on benthic organisms, but not necessarily in proportion to the abundance of these invertebrates in the benthos. *Corophium salmonis,* a tube-dwelling amphipod, was overall the most important food item. Other important prey included the clam *Corbicula manilensis* and eulachon *Thaleichthys pacificus* eggs in May. Results from stomach analyses suggested that food may be limited for juveniles, at least in certain areas of the river, in September and October.

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Dungeness Crab

The Dungeness crab (Cancer maqister) is one of the most important commercial and recreational species of the Columbia River estuary. In 1983, prior to the start of proposed entrance-channel dredging, the Division began a 2-year study on Dungeness crabs in the estuary. The CZES Division's initial studies of the distribution, abundance, and size class structure of Dungeness crabs in the Columbia River estuary showed an extensive population of Dungeness crabs. The studies also identified the temporal occurrence of large numbers of 0+ age crabs (young-of-the-year, YOY). However, comprehensive information regarding the distribution, abundance, size-class structure, and movements of crabs between the ocean and the estuary was not available in the early 1980s.

Specific objectives of the study were to describe the Dungeness crab's estuarine distribution, abundance, size-class structure, and location and timing of movements across the Columbia River bar (entrance channel at the mouth of the river). Since crabs moving between the ocean and the Columbia River estuary must pass over the bar, the effects of dredging on crabs could be significantly detrimental.

Sampling for the 2-year study began in November 1983 and was completed in October 1985. Results showed that crabs were generally distributed from the bar to River Km 27. Overall, crab densities on the bar were significantly less than densities in the area upstream from the bar. The YOY crabs were captured in the estuary beginning in May 1984 and 1985. During the late spring and summer, YOY densities increased on the bar, but there was no corresponding increase in YOY densities upstream from the bar. Dungeness crabs were collected only in subtidal areas of the estuary during the 2-year study.

Because of large annual fluctuations in crab densities observed at some frequently dredged estuarine areas during the study period, the Division continues to sample at some of the established stations. The objective of the extended study was to describe the abundance and size-class structure of Dungeness crabs in or near frequently dredged areas in the Columbia River estuary, including the bar and three sites upstream from the bar. Results of these observations have expanded the overall data base on Dungeness crabs in the estuary, specifically in areas subject to frequent dredging. They have also provided additional information for crab entrainment studies.

Results of the initial 2-year study and the extended study show that the Columbia River estuary provides valuable habitat for Dungeness crabs, and that crab densities fluctuate temporally and spatially. Densities of crabs on the bar are extremely dependent on the immigration of early instar crabs or megalops larvae into the estuary during spring and summer. Although densities fluctuated annually, seasonal patterns were identified at some sites. This information about the Columbia River estuary aids resource managers in making decisions about dredging schedules and methods to minimize impacts on Dungeness crabs.

CZES Division personnel continue to sample regularly at three estuarine sites in or near frequently dredged areas.

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Parasitic Copepod

Two species of Columbia River estuary mysids, _Neomysis mercedis_ and _Alienacanthomysis macropsis,_ were found with a parasitic copepod infesting the marsupium of the female mysids. _Hansenulus trebax,_ a new genus and species of copepod, was described and recorded as an ectoparasite within the marsupia of four species of mysids. Infected mysids were collected mostly from the Columbia River estuary. Two copepod-bearing mysids were collected near San Juan Island, Washington, and one each from near Kodiak Island, Alaska, and the eastern Bering Sea. The relationships between the life histories of Columbia River mysids and an ectoparasitic copepod and their spatial and seasonal distributions were examined. The remarkably high incidence of parasitism remained stable throughout the year in spite of seasonal fluctuations in the two mysid populations. _Neomysis mercedis_ is an important component in the diet of fishes in other estuaries along the Pacific Coast; however, it does not appear to be as important a food resource in the Columbia River estuary. This may be due to the parasite, which probably has a significant effect on the population growth of the mysid hosts.

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ENVIRONMENTAL EFFECTS

Gas Supersaturation in Loner Columbia River

Gas bubble disease (GBD) in freshwater fishes, resulting from supersaturation of dissolved atmospheric gases in water, has been studied by investigators since the early 1900s. In the Columbia and Snake Rivers, GBD became evident in the 1960s and was attributed to supersaturation of dissolved gases caused by pressure from high volumes of water flowing over spillways at dams. Gas levels of over 140% saturation were not uncommon, and levels of 110% have been shown to be potentially lethal to fish.

In the early 1970s, extensive efforts were made to decrease levels of supersaturation created by spill including 1) increased water storage in the upper reaches of the river basin, 2) increased electrical generation at dams, and 3) installation of flow deflectors on the spillways of several dams. As a result of these actions, little evidence of GBD in salmonids was observed in the late 1970s.

During the 1980s, however, with the implementation of increased spill at dams to improve passage of juvenile salmonids, diurnal fluctuations in supersaturation were created within the Columbia River system. The COE and the CZES Division established a field bioassay and monitoring program to evaluate the impacts of intermittent dissolved gas supersaturation on both juvenile and adult salmonids. The reservoir behind The Dalles Dam was selected as the primary evaluation site because daily spill was expected at the next upstream dam (John Day Dam). Conditions and impacts in 1985 and 1986 were described and compared with results from earlier studies. Criteria for national and state dissolved gas standards were reevaluated informally to assess whether current violations of supersaturation standards in the Columbia River Basin necessitated changes in the established criteria. Changes in water management policies and more research on biological impacts were discussed. Managers of state and federal fishery and water quality agencies were informed regarding research conclusions and the severity and frequency of supersaturation under present day conditions.

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G

Mount St. Helens Eruption

As a result of the 18 May 1980 eruption of Mount St. Helens (Washington), large quantities of ash and sediment were suddenly washed into the Columbia River and its estuary. Water quality, particularly turbidity, changed dramatically. Since increased turbidity is one of the major water quality impacts of dredging and dredge-disposal, studying the effects of this dramatic event offered an opportunity to gain insight into how dredging operations could influence estuarine usage by juvenile salmonids and other estuarine fishes.

Although there has yet to be a comprehensive long-term physical, chemical, and biological monitoring program in the Columbia River estuary, the eruption of Mount St. Helens fortuitously occurred during the sampling phase of the Columbia River Estuary Data Development Program (CREDDP, see ECOSYSTEM ASSESSMENTS above). Although not destined to be a long-term study, CREDDP included the most comprehensive, broad-scale biological sampling of the estuary to date. Accordingly, CZES Division researchers used the available CREDDP results, as well as data from other selected studies, as a baseline against which to compare post-eruption monitoring results. These analyses produced some general observations and conclusions. After the eruption and the resulting high turbidities in the estuary, there were major changes in the abundances and feeding habits of selected fishes. For example, subyearling chinook salmon were less abundant in open-water areas of the upper estuary, more abundant in open-water areas of the central and lower estuary, and consumed fewer amphipods (*Corophium* spp.). Also, amphipod densities at selected locations in the estuary were significantly lower after the eruption. Since dredging often produces high turbidities, the eruption can be viewed as a natural, albeit extreme, example of how high turbidities can alter abundances and feeding habits of estuarine fishes.

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Effects of Fluoride on Fish Passage

The upstream migration of adult spring chinook salmon in the Columbia River has been subject to unusually long delays at John Day Dam. During the spring migration period, average passage times for radio-tagged salmonids at John Day Dam were 158 and 156 hours in 1979 and 1980, respectively. In contrast, average passage time at Bonneville Dam was less than 48 hours and at The Dalles Dam it was less than 24 hours. In addition, passage times for salmonids in the fall of 1982 were twice as long at John Day Dam as they were at The Dalles and McNary Dams. The delay of nearly 1 week at John Day Dam appeared to contribute to increased mortality and may have affected the spawning success of migrating adult salmonids.

Migratory delays at John Day Dam were not decreased appreciably by changes in fishway entrance locations, water discharge volumes or configurations, or turbine operating conditions. The lack of response by migrating salmonids to flow alterations below the dam focused attention on the possibility that something in the water might be causing fish to avoid the fishways and delay their passage.

In 1982, preliminary studies conducted by CZES Division personnel assessed the distributions of many pollutants near John Day Dam. The results of this investigation suggested that the fish-passage delays might be related to contaminants discharged at an aluminum smelter outfall located on the Washington shore 1.6 km upstream from John Day Dam. In particular, high concentrations of fluoride in the vicinity of John Day Dam (0.3-0.5 mg/L in 1982) prompted investigators to focus sampling and research efforts on this contaminant.

In 1983 and 1984, behavior tests were conducted in which over 600 returning salmonids (chinook, coho, and chum, O. keta, salmon) were captured and tested with different concentrations of fluoride in a two-choice flume located in the spawning channel of Big Beef Creek, Washington. The conclusion from these experiments was that the behavior of upstream-migrating adult salmon would be adversely affected by fluoride concentrations of about 0.5 mg/L and that concentrations of 0.2 mg F/L were at or below the threshold for fluoride sensitivity of chinook and coho salmon.

Beginning in 1983 and continuing through 1986, fluoride discharges from the aluminum plant were greatly reduced. This was initially due to modifications in the plant's pollution-discharge system. However, it was also during this period that the Washington Department of Ecology (WDOE) took an active interest in the results of the CZES Division's water quality and behavior tests. The WDOE lowered significantly the discharge limitations for a number of contaminants, including fluoride, in the aluminum plant's wastewater discharge permit. With the reduction in fluoride discharged from the aluminum plant, there was a corresponding drop in fluoride concentrations in the river near the outfall and John Day Dam. Concurrently, fish passage delays and interdam losses of adult salmon decreased to acceptable levels.

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Effects of Enhanced Ultraviolet Radiation on *Zooplankton*

Ultraviolet (UV) radiation **in** the middle wavelength range (285-315 nm, UV-B) has important and practical biological effects. This radiation is of particular interest because it occurs in normal sunlight and would increase if the UV-absorbing stratospheric ozone layer were reduced. Contamination of the ozone layer is among the most complex environmental issues and is currently perceived as global in scope. There is controversy regarding the magnitude of predicted changes in ozone concentration, and considerable uncertainty and concern remain about the resulting increases in incident solar UV-B radiation and the risk of harmful biological effects.

From 1976 to 1984, the Division conducted research on the effects of enhanced solar radiation on near-surface marine zooplankton. Zooplankton include nearly all groups of aquatic animals, at least for some phase in their life-history, such as the egg or larval stage. Zooplankton are found at all depths, depending on species and season, but are most abundant in the sunlit upper 100 m, where the bulk of their food, including the phytoplankton, is found. Zooplankton are critical components in aquatic food webs, concentrating in larger animals, including fish and shellfish which are the basis of important fisheries.

Different species of shrimp and crab larvae, euphausiids, and copepods were collected from the near-surface layer and exposed to various levels of simulated solar UV radiation. Comparisons between solar and artificial spectra were based on spectroradiometric measurements. Generally, the zooplankton species tested tolerated UV-B irradiance up to threshold levels with no significant reduction in survival or developmental rates. Beyond the established threshold levels, activity, development, and survival rapidly declined. The apparent UV radiation thresholds are near present incident UV radiation levels, and our findings were consistent with the conclusion that solar UV radiation, even at present levels, may control the seasonal vertical distribution of many of these animals. In addition to determining the dose and dose-rate responses of these zooplankton species, the questions of photorepair and behavioral response were also investigated. The results of these studies demonstrated the occurrence and light requirements of photorepair mechanisms in several important zooplankton species. They also revealed the apparent inability of many of these species to detect and avoid harmful levels of UV-B irradiance.

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Effects of Spectral Irradiance on Early Development of Salmon

It is well known that solar and artificial light affect the viability and hatching of salmon eggs as well as the activity and growth of alevins and fry. This is of particular concern in the unnatural setting of the fish hatchery. Although a number of investigations have been conducted to evaluate the effects of light on the early developmental stages of salmon, very little is known regarding effects of specific wavelength bands and specific intensities emitted by different lights. This lack of knowledge has been largely due to a lack of spectroradiometric instrumentation for precisely evaluating wavelength distributions of energy from various light sources. By quantifying total spectral irradiance or irradiance within a specific wavelength band, it is possible to discern more accurately what kind of light is biologically harmful, benign, or perhaps beneficial.

From 1980 to 1983, experiments were conducted by CZES Division personnel during fall, winter, and early spring at the Northwest Fisheries Science Center in Seattle, Washington. Eggs and milt were obtained from fully mature fall chinook salmon returning to Portage Bay (Lake Union), the site of the center. In the experiments, freshly fertilized eggs, alevins, and fry were exposed to artificial light sources of different spectral distributions and irradiances. Measurements of spectral irradiance were made with a spectroradiometer which measures instantaneous irradiance at each wavelength (W/m^2), and this was converted to daily irradiance (kJ/m^2).

Survival, eyeing, hatching, and length and weight data from the 3-year study suggested that 1) all light is not harmful to chinook salmon eggs, alevins, and fry; 2) ultraviolet light (285-390 nm) of spectral irradiance above 10^{-3} W/m^2 (8 h/d) is harmful to chinook salmon eggs, alevins, and fry; 3) visible light (390-800 nm) of spectral irradiance above 10^{-2} W/m^2 (8 h/d) is harmful to chinook salmon eggs; 4) chinook salmon eggs are more vulnerable to both ultraviolet light and visible light than are alevins and fry; and 5) semidarkness or the irradiance of pink fluorescent lamps may benefit chinook salmon fry in terms of weight gain. Results indicated that chinook salmon eggs may be exposed to 50-100 kJ/m^2 of artificial light daily from incandescent bulbs, filtered pink fluorescent lamps, or conventional fluorescent room lighting without being adversely affected in their viability or hatching rate or the size of the fry. An approximate threshold for safe combinations of daily ultraviolet (UV) and visible irradiance (VIS) for chinook salmon eggs, alevins, and fry may be determined from the expression 150 = 150(UV) + VIS.

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TECHNOLOGICAL CONTRIBUTIONS

Coded Radio Tag

Miniature radio-frequency electronic tags, which are placed in fish, provide a means for researchers to track fish movements and study their behavior. A limiting factor in the number of radio tags that can be used in a study is the number of frequencies that tag-monitoring receivers can differentiate. Attempts to increase the number of fish that could be tracked in a study by producing several pulse rates on each frequency have not succeeded in the past. Pulse rate separation problems occurred when several tags of the same frequency were in the same area. When frequencies are separate, tags with faster pulse-rate frequencies cause higher battery drain, producing differences in tag life.

Electronics personnel of the CZES Division developed and tested a radio telemetry system that provides individual coding of several tags on the same frequency with equal tag life. This system greatly increases the number of fish that can be tracked. The components include radio transmitter tags for juvenile and adult salmonids, a broad band radio receiver, a pulse decoding microprocessor, and paper and magnetic tape data output units.

Radio transmitters are crystal controlled for frequencies between 30.170 and 30.250 MHz. Components for adult salmonid tags are miniature integrated circuits, and the juvenile tag utilizes hybrid chip technology. When pulsed at 600 ms, tag life is 30 days for the adult and 7 days for the juvenile. Individual codes for each tag are obtained by dividing the radio pulse into two parts, then setting the time between the parts differently for each tag on an assigned frequency. The code for an individual tag is a four digit number that begins with the frequency transmitted (Channel Number 1-9) followed by the time period between pulse parts.

The receiver simultaneously monitors all channels and sets a flag when a channel is active. The monitor microprocessor scans the channels until a flag is found, then stops and checks the active channel for a period longer then the pulse period of the tag. The monitor then checks pulse length and sequence, measures the code period, and outputs the data to the recording devices. A paper data recorder provides real-time quality control for the system, and a digital cassette data recorder provides the permanent storage medium for computer entry and subsequent data analysis. Data recorded for each pulse includes date, time, channel number, code number, antenna number, and site location number. In situations where tags may be on the monitor for extended periods of time, there are provisions in the monitor to reduce the number of records stored and to delay monitor operation for a set period of time.

There are three significant developments in the creation of this tracking system: coincident pulse circuitry, programmable read only memory (PROM) firmware for radio frequency (RF) noise reduction, and pulse reconstruction circuitry. First, the coincident pulse circuitry eliminates information when pulses from two or more tags overlap. As long as no two tags have the same pulse interval, the overlapping pulses will separate and the proper code will be recorded. Second, since RF noise on tracking frequencies can reduce the sensitivity of tracking monitors, even low level RF emissions can be a problem with a highly sensitive RF receiver. The monitor has three microprocessors producing low level RF noise. This RF noise combines with software-generated noise to produce noise with frequencies that may be the same as the tracking frequencies, thereby causing interference. Consequently, several of the program sequences for the monitor PROMs are specifically designed to eliminate RF noise or to shift the frequency to an area outside of the tracking frequencies.

The third significant development is the pulse reconstruction circuitry. Tag signals from the limits of antenna range (distance or depth) are broken when checked by the pulse sequence logic. The pulse reconstruction circuitry removes breaks in the pulse to produce appropriate pulse characteristics. In effect, this circuitry adds 3 db of sensitivity to the monitor.

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Genetic Stock Identification (GSI)

Genetic research on fruit flies and humans in the mid-1960s established the technical groundwork for multilocus surveys of population genetics of plants and animals. These earlier studies showed how protein gel electrophoresis could be cost-effective when screening for simple Mendelian variability at a large number of protein-coding loci (characters) in animal populations. Questions dealing with patterns and levels of genetic variation within and among populations could be addressed and quantified. In other words, researchers could look for differences among neighboring populations and explore how levels of genetic variation vary from population to population. Protein electrophoresis examines allozyme (alleles of enzymes) variation. Allozyme technology by CZES Division personnel during the 1970s has progressed from the ability to identify several loci to the classification of over 30.

By 1980, the technical foundations were established for using allozyme characters for genetic stock identification (GSI) of salmon populations in mixed-stock fishery situations. Genetic stock identification depends on several attributes of a mixed-stock population: 1) a multilocus baseline for all of the major contributing stocks can be generated, 2) genetic differences can be identified between stocks in the baseline, 3) allele frequencies (e.g., the genetic baseline) are stable through time, 4) the alleles are evolutionarily neutral, and 5) an adequate number of fish can be sampled and studied electrophoretically from the mixed-stock fishery. By 1980, fishery managers had begun using GSI to estimate stock compositions for a few mixed stock fisheries:

chinook salmon in the Columbia River; sockeye salmon in Cook Inlet, Alaska; and chum salmon in Puget Sound.

From 1981 to 1982, two studies were completed by Division personnel that were instrumental in the development and initial acceptance of GSI as a management tool. First, the reliability of the method was demonstrated. In this study, the GSI model was used to accurately estimate the contributions of 14 spring chinook salmon hatchery stocks in the Columbia River to four "blind" mixtures. Second, a 31-locus baseline was constructed from 81 stocks ranging from Sacramento River, California, through Vancouver Island, British Columbia. This extensive baseline allowed the application of GSI to a commercial troll fishery off the Washington coast in May 1982. This also marked the beginning of an extended period of cooperative GSI projects by the CZES Division and the Washington Department of Fisheries (WDF). Each year since 1982, GSI has been instrumental in the management of chinook salmon fisheries in the Columbia River and off the Washington coast.

In 1983, GSI was used to monitor the stock composition of commercial, treaty, and sport fisheries of chinook salmon. Areas monitored ranged from the Strait of Juan de Fuca southward along the Washington coast through the mouth of the Columbia River to the northern coast of Oregon. **Beginning in** 1984, and continuing through 1986, the west Vancouver Island troll fishery was also added. The Canadian Department of Fisheries and Oceans (CDFO) became an active collaborator with the Division and WDF in these studies. Improvements in data handling and statistical procedures and expansion of baseline development in southern Oregon, the

Columbia River Basin, and British Columbia were also emphasized during these years.

From 1980 to 1985, the Division worked with the NMFS Auke Bay Laboratory (ABL) on related GSI issues in southeast Alaska. ABL was interested in baseline development for sockeye and chum salmon stocks in southeast Alaska, and they supplied the Division with tissues for electrophoretic study. In 1985, a multilocus description of allozyme variability in sockeye salmon in North America was published by Division personnel. Sockeye salmon have few polymorphic (multi-allelic) loci, and the Division worked with ABL biologists in augmenting a GSI baseline with other characters (e.g., scales and parasites) for use in mixed fishery situations. The chum baseline was presented jointly with ABL at a GSI meeting.

In 1987, Division personnel cooperated with CDFO and WDF in a project to estimate stock contributions to sport fisheries in Georgia Strait.

Various papers published by CZES Division authors in the late 1980s summarized the general nature and use of GSI technology and related topics in population genetics. These documents provide the following: explanation of the GSI model in general terms and demonstration with three simple applications; laboratory interpretations of allozyme banding patterns of salmon; description of statistical/mathematical advances in mixture analyses; provision of technical details for staining billions of enzymes in salmon; interpretation of temporal changes in allele frequencies; dis2tribution of alleles in chinook salmon populations in North America; description of three areas of genetic research that flow from genetic baselines; and description of levels of genetic variability in Columbia River Basin stocks with respect to conservation and management issues.

With the general increase in GSI activities throughout the 1980s, an interagency group was formed to help standardize techniques and data base applications. Two to three GSI coordinating meetings are held per year, with the host responsibility rotating among the participating laboratories. Meetings were held by the University of California at Davis; WDF; CZES Division; the Pacific Salmon Commission (Vancouver, British Columbia); ABL; and the U.S. Fish and Wildlife Service in Anchorage, Alaska. Important results of these meetings include a process for "sponsoring" new loci or alleles to be included in standardized scoring protocols (chinook and chum salmon only) and standardized locus, allele, and, to some degree, buffer nomenclature. The CZES Division is responsible for the standardized chinook salmon baseline. This includes tabulating the new baseline data yearly and entering these data into the coastwide data set following statistical evaluations. The current baseline for chinook salmon uses 23 loci and includes 183 stocks or stock groups. Division personnel are also responsible for coordinating the Asian portion of a specieswide data set for chum salmon.

From 1987 to 1990, the CZES Division worked with CDFO biologists to expand the chinook salmon baseline in the Fraser River. The CZES Division now has data for about 40 loci from 63 stocks in the Fraser River. Test fisheries were conducted from 1987 to 1989 in the lower Fraser River and analyzed by the Division (1988 data only). The results have provided useful information about the presence of upper, middle, and lower river stocks in this test fishery.

The present status of CZES GSI research can be summarized as follows:

- Chinook Salmon: The coastwide baseline extends to the northern coast of British Columbia. It is anticipated that the Skeena River area will be finished in the next 3 years with the cooperation of CDFO and WDF.

- Coho Salmon: This species is a focus of concern under U.S.-Canada negotiations. Allozymic variation in coho salmon is being evaluated and baseline work continues.

- Chum Salmon: CZES Division personnel are initiating field and laboratory research with Japanese and Russian scientists to fill out an Asian baseline for use in high seas fisheries. This work will be coordinated with WDF and ABL to establish a standardized genetic baseline for the species.

- Sockeye Salmon: An allozyme survey is being completed for the first two brood years of sockeye salmon in the Lake Cle Elum restoration project.

- Steelhead: Work continues with steelhead stocks in the Snake River Basin to evaluate hatchery supplementation. The CZES Division is the lead agency in setting up a coastwide standardized baseline for this species.

- High Seas Application: The Asian portion of the specieswide baseline for chum salmon will be expanded in 1989-90. Data have been gathered for about 155 stocks or stock groups, and it is anticipated that data will be added for 70 loci for up to 15 Japanese populations and several Russian populations. Chum salmon data have been used for several mixture analyses and will be used more in the future. The future also includes working with the Fishery Agency of Japan and CDFO to do GSI estimates on samples from test fisheries on the high seas.
- DNA Research: A proposal has been submitted for consideration under the High Seas Project to establish a DNA research laboratory at the Northwest Fisheries Science Center.

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Passive Integrated Transponder (PIT) Tag

A major cooperative research and development program was undertaken by the CZES Division in 1984. The program is directed at evaluating the technical and biological feasibility of the implantable passive integrated transponder (PIT) tag in salmonid research. The PIT tag is an electronic tag 12 mm long and 2 mm in diameter that can be coded with one of 35 billion unique codes. The tag can be automatically detected and decoded in situ, eliminating the need to anesthetize, handle, restrain, or sacrifice fish during data retrieval.

In 1984, juvenile and adult salmon were injected with sham (nonfunctional) PIT tags to determine suitable anatomical areas for tag placement, to develop tag injection techniques, and to determine the effect of the tag on growth and survival. The body cavity was selected as the best area for tag placement for most applications.

Work continued in 1985 to evaluate the effect of the tag on growth and survival of juvenile fish and to further refine tagging techniques., Functional polypropylene-encapsulated PIT tags were used for the first time. In addition, prototype juvenile and adult PIT-tag monitoring systems were evaluated in field tests in the Columbia River Basin. Although these studies supported the feasibility of the PIT-tag system, an unacceptable tag failure rate (10%+) and a high tag rejection rate (to 15%) were noted. This poor performance was attributed to the polypropylene shell of the tag.

In 1986, a new glass encapsulated PIT tag having a smooth, leak proof, and seemingly biologically inert case was evaluated. This glass-encapsulated version proved to be highly reliable in tagging fish weighing as little as 3 g. Results of laboratory tests indicated a high tag retention rate (99%+) and a low tag failure rate (1% or less). Behavioral tests showed no measurable effect of the tag on juvenile salmonids.

Field testing of PIT-tag systems to monitor the in-river movements of juvenile and adult salmonids continued in 1986. The monitoring systems were installed and tested at McNary Dam on the Columbia River and Lower Granite Dam on the Snake River. Results showed that fish injected with the PIT tag and released into the river can be individually recognized by detecting/recording devices when passing fish collection facilities at hydroelectric dams. Since 1986, additional PIT-tag monitoring systems have been installed at Little Goose Dam on the Snake River and Prosser Dam on the Yakima River.

During the 1987, 1988, and 1989 field seasons, tests were conducted on the Columbia River comparing the PIT tag to both traditional coded wire tag and freeze-brand fish identification systems. These studies indicated no statistical differences in the survival, growth, or behavior of PIT-tagged fish. In addition, it was shown that because of high precision, accuracy, and efficiency in tag-reading, many studies could be conducted with 95 to 98% fewer fish than those using traditional tagging or marking systems. This reduction in numbers of fish required for research projects is an important advantage and reflects the unique characteristics of the PIT tag.

Additional tests of monitoring systems at dams were made during 1987-89 to improve tag reading efficiency, equipment reliability, and functionality. Results of tests showed that tag reading efficiency was over 95% and that reading accuracy was over 99% (correct tag code read). A prototype system was developed, installed, and evaluated at Lower Granite Dam to separate PIT-tagged from non-PIT-tagged fish. The system, which functioned satisfactorily, is considered critical to fish transportation and many other proposed studies. Modifications to the separation system were made in 1990 that improved its performance. Alternative means of monitoring PIT-tagged fish on release from hatcheries or other holding or rearing areas (e.g., pumping fish or passing fish volitionally through monitors) were developed and are being evaluated.

A prototype data base, for Columbia River Basin PIT-tag information, was established in 1988. A permanent data base was established with the Pacific States Marine Fisheries Commission in Portland, Oregon, in 1990. The new system will be functional in 1991. A PIT-tag technical work group was formed in 1988 to establish data and procedural specifications and to make recommendations pertaining to overall PIT-tag system development. Both software and hardware modifications were made to PIT-tag monitoring and tagging programs. These changes, coupled with the development of a semiautomatic tag injection system, resulted in a standardized tagging system. The system is universal in that it can be operated on either AC or DC power.

Research on the PIT tag is continuing and will focus on extending the monitoring range of the system, evaluating long-term tag retention and operation, and determining possible tag effects on behavior of fish. New PIT-tag monitoring sites (e.g., other Columbia River Basin dams) are being planned to expand the usefulness of the system.

The juvenile salmon PIT-tag system is now considered to be in its final developmental stages. Currently, the system is being used by state, federal, tribal, and private fishery managers and researchers concerned with salmonid stocks throughout the Columbia River Basin. Several project elements, including data base management and systems operation and maintenance, are being transferred to other agencies as the system is refined.

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